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(54) **GEOMAGNETIC SENSOR**

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G01V 3/40 (2006.01)
(Continued)

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CPC ***G01V 3/40*** (2013.01); ***G01C 17/30*** (2013.01); ***G01R 33/028*** (2013.01); ***G01R 33/04*** (2013.01)

(58) **Field of Classification Search**
CPC .. G01R 19/0092; G01R 15/18; G01R 15/20; G01R 15/148; G01R 15/183; G01R 15/207; G01R 19/20; G01R 33/02; G01R 33/09; G01R 19/00; H01F 38/28; H01F 38/32
USPC .... 324/244–252, 260, 344, 127, 117 R, 324/117 H, 713
See application file for complete search history.

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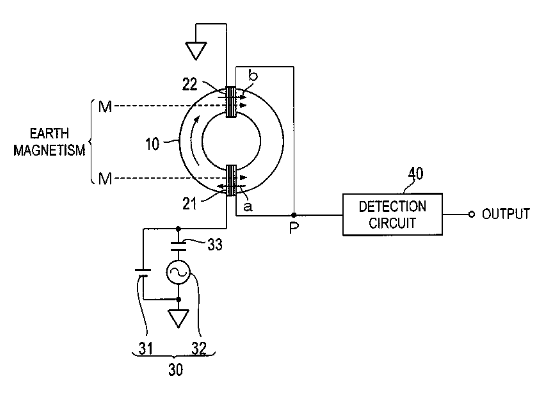
(57) **ABSTRACT**

A geomagnetic sensor includes: a core that constitutes a closed magnetic circuit; a pair of coils that are wound around the core in positions facing each other and are connected in series to generate magnetic flux in the same circumferential direction in the core; an excitation power supply that applies an alternating current with a superimposed direct current to the pair of coils; and a detection circuit that is connected to a connection point of the pair of coils. Unlike a conventional flux gate type geomagnetic sensor, it is not required to excite the core until the core is magnetically saturated, and it is therefore possible to reduce power consumption.

9 Claims, 4 Drawing Sheets



(51) **Int. Cl.**

G01R 33/028	(2006.01)
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G01C 17/30	(2006.01)

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FIG. 1

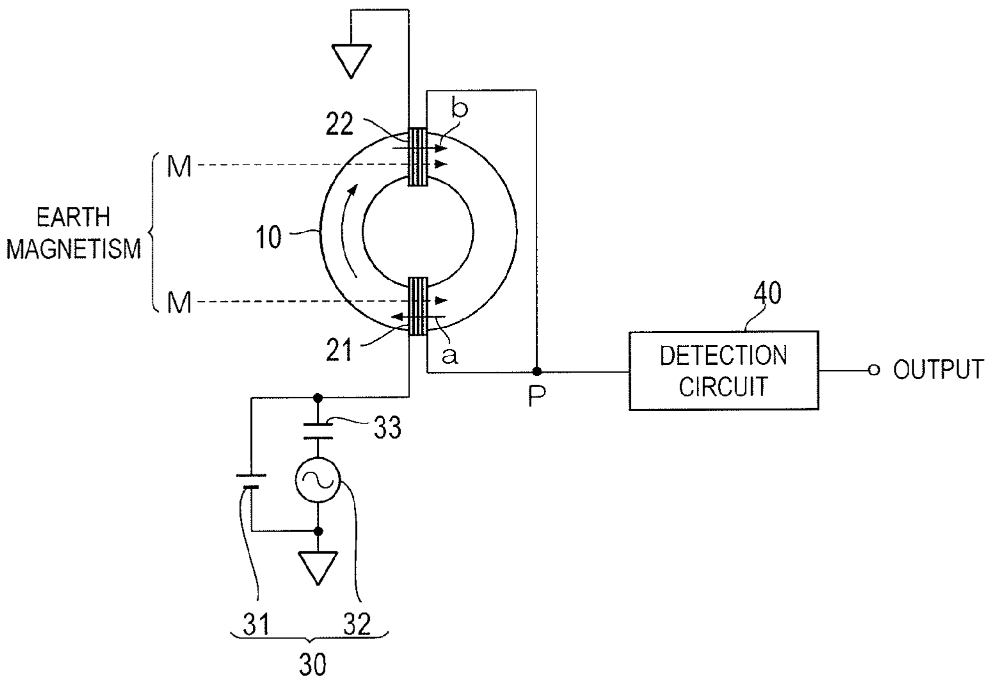
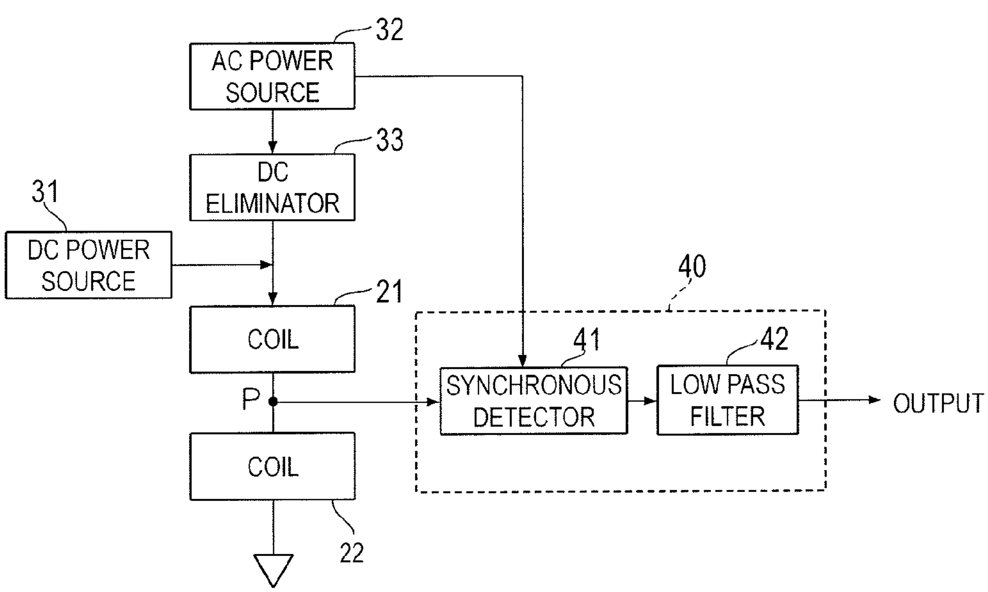

22
b
M
EARTH
MAGNETISM
10
M
21
a
40
DETECTION
CIRCUIT
OUTPUT
P
33
31
32
30

FIG. 2


32
AC POWER
SOURCE
33
DC
ELIMINATOR
31
DC POWER
SOURCE
21
COIL
40
41
42
SYNCHRONOUS
DETECTOR
LOW PASS
FILTER
OUTPUT
P
COIL
22

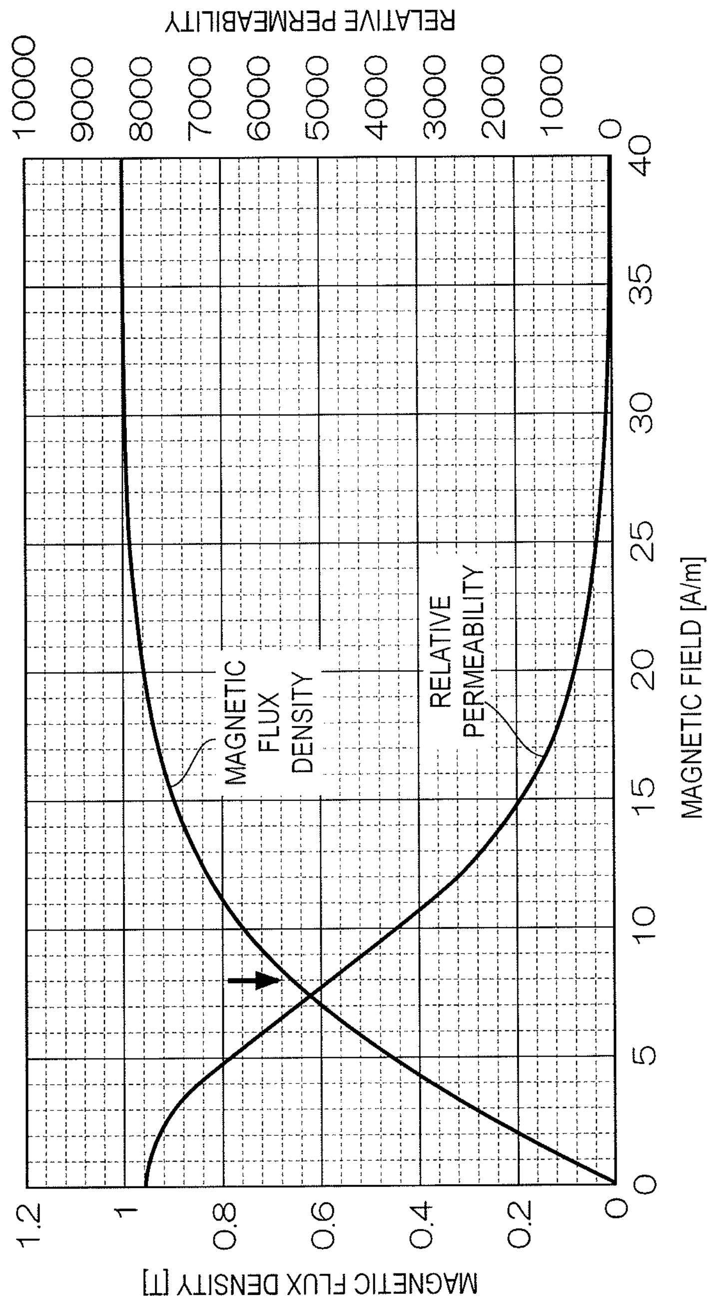

RELATIVE PERMEABILITY
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
MAGNETIC FLUX DENSITY [T]
1.2
1
0.8
0.6
0.4
0.2
0
MAGNETIC FIELD [A/m]
0
5
10
15
20
25
30
35
40
MAGNETIC FLUX DENSITY
RELATIVE PERMEABILITY

FIG. 3

FIG. 4

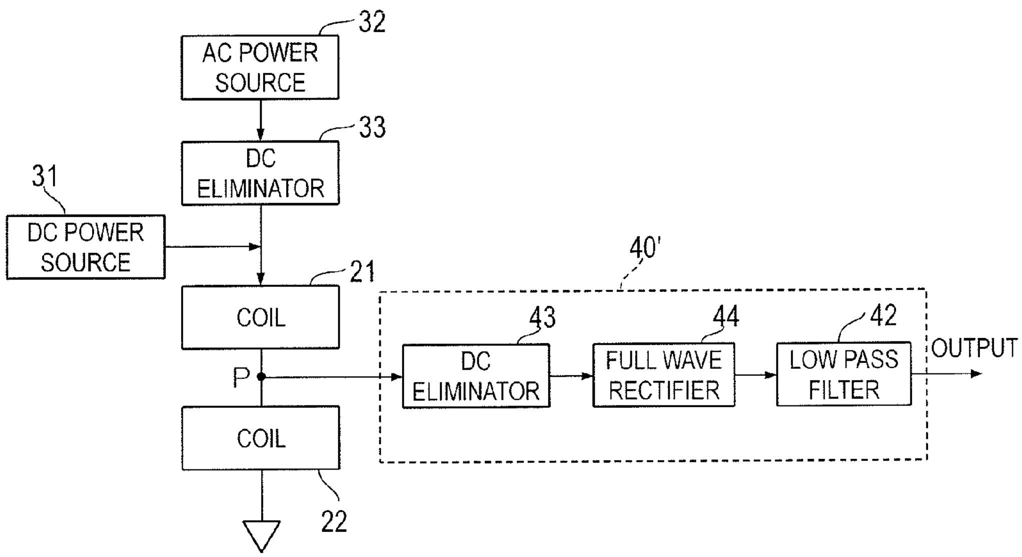

32
AC POWER SOURCE
33
DC ELIMINATOR
31
DC POWER SOURCE
21
COIL
P
COIL
22
40'
43
DC ELIMINATOR
44
FULL WAVE RECTIFIER
42
LOW PASS FILTER
OUTPUT

FIG. 5

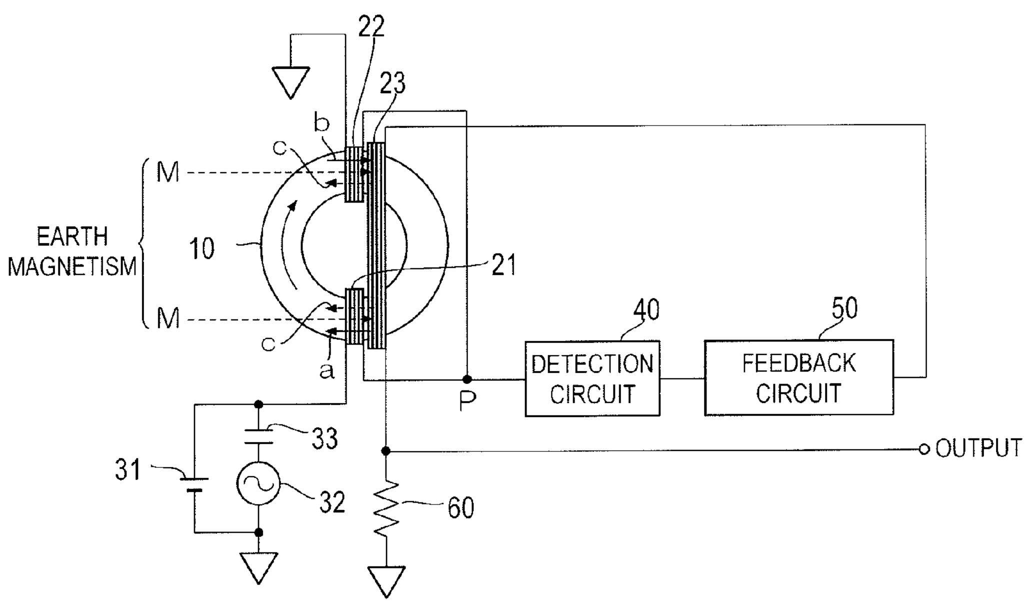
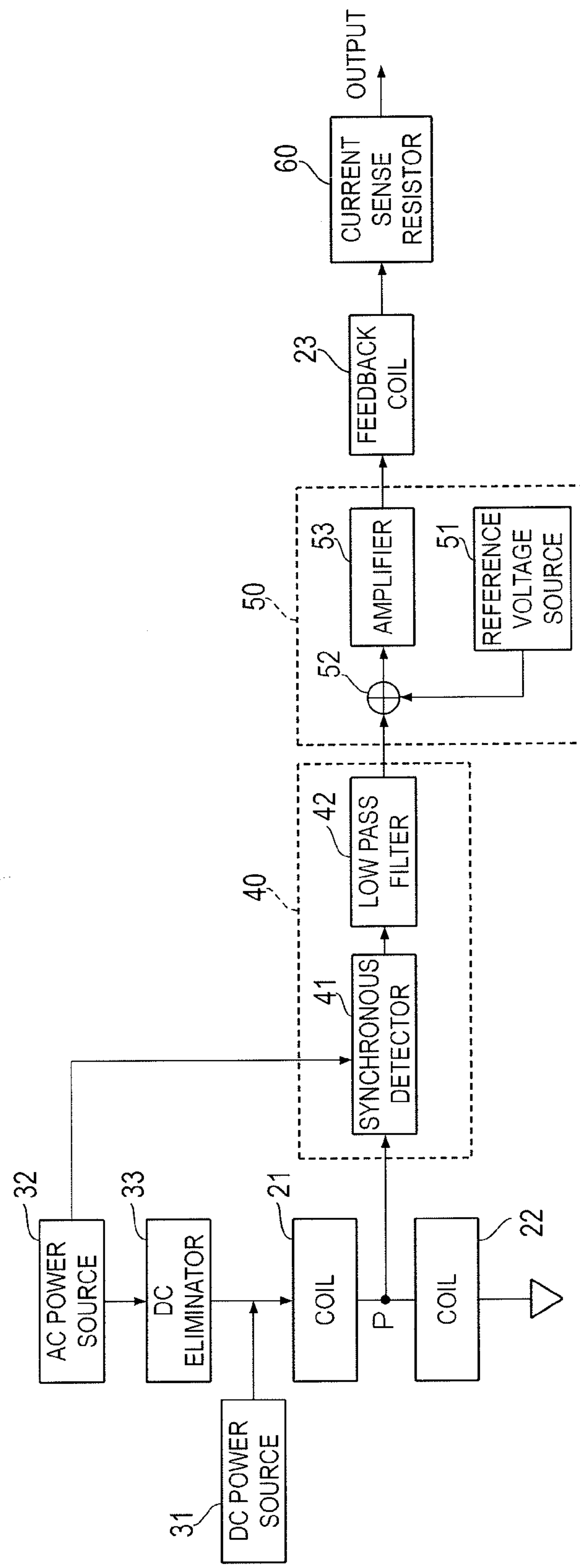

22
23
b
c
M
EARTH MAGNETISM
10
21
M
c
a
40
DETECTION CIRCUIT
50
FEEDBACK CIRCUIT
P
33
31
32
OUTPUT
60

FIG. 6


OUTPUT
60
CURRENT SENSE RESISTOR
23
FEEDBACK COIL
50
53
AMPLIFIER
51
REFERENCE VOLTAGE SOURCE
52
40
42
LOW PASS FILTER
41
SYNCHRONOUS DETECTOR
32
AC POWER SOURCE
33
DC ELIMINATOR
21
COIL
P
COIL
22
31
DC POWER SOURCE

GEOMAGNETIC SENSOR

TECHNICAL FIELD

The present invention relates to a geomagnetic sensor that measures the earth magnetism.

BACKGROUND ART

Conventionally, as a geomagnetic sensor that measures the earth magnetism, a flux gate type (FG type) geomagnetic sensor is known widely (for example, refer to Patent Literature 1).

Although being capable of high precision measurement of the earth magnetism, the flux gate type geomagnetic sensor has a problem in that, because a core with an exciting coil wound therearound has to be magnetically saturated with an AC current, namely an alternating current, the excitation current increases and power consumption is large.

PRIOR ART LITERATURE

Patent Literature

Patent literature 1: Japanese Patent Application Laid Open No. 2009-92381

SUMMARY OF THE INVENTION

Problems to be Solved by the Invention

It is an object of the present invention is to provide a geomagnetic sensor being capable of reducing power consumption.

Means to Solve the Problems

According to the present invention, a geomagnetic sensor includes: a core that constitutes a closed magnetic circuit; two coils that are wound around the core in positions facing each other and are connected in series to generate magnetic flux in the same circumferential direction in the core; an excitation power supply that applies an alternating current (AC) with a superimposed direct current (DC) to the two coils; and a detection circuit that is connected to a connection point of the two coils.

Effects of the Invention

According to the present invention, unlike a conventional flux gate type geomagnetic sensor, it is not required to excite a core until the core is magnetically saturated, that is, without magnetically saturating the core, it is possible to measure the earth magnetism with high precision, and it is therefore possible to reduce power consumption compared with the conventional sensors.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a diagram schematically illustrating a configuration in a first embodiment of a geomagnetic sensor according to the present invention.

FIG. **2** is a block diagram illustrating a functional configuration in the first embodiment of a geomagnetic sensor according to the present invention.

FIG. **3** is a graph illustrating a B-H curve and relative permeability.

FIG. **4** is a block diagram illustrating a functional configuration in a second embodiment of a geomagnetic sensor according to the present invention.

FIG. **5** is a diagram schematically illustrating a configuration in a third embodiment of a geomagnetic sensor according to the present invention.

FIG. **6** is a block diagram illustrating a functional configuration in the third embodiment of a geomagnetic sensor according to the present invention.

DETAILED DESCRIPTION OF THE EMBODIMENTS

Descriptions are given below to embodiments of the present invention.

FIG. **1** schematically illustrates a configuration in a first embodiment of a geomagnetic sensor according to the present invention, and

FIG. **2** illustrates a functional configuration of the geomagnetic sensor illustrated in FIG. **1** as a block diagram.

A core **10** constituting a closed magnetic circuit is made of a highly permeable magnetic material, such as permalloy; the core is assumed to be a toroidal core in this case. Coils **21**, **22** are wound around the core **10** in positions facing each other with the coil axial centers parallel to each other. The coils **21**, **22** are wound around in the same direction viewed from the center of the core **10**, and are connected in series to generate two pieces of magnetic flux in the same circumferential direction in the core **10** when a current is applied to the coils **21**, **22**.

To one end of the one coil **21**, an excitation power supply **30** is connected. The excitation power supply **30** includes a DC (direct current) power supply **31** and an AC (alternating current) power supply **32**, and is capable of applying an AC current with a superimposed DC current to the coils **21**, **22**. In FIG. **1**, **33** denotes a DC eliminator (capacitor).

A DC current is applied to the coils **21**, **22** by the DC power supply **31**, which generates two pieces of DC magnetic flux in the core **10**. In FIG. **1**, arrows a, b exemplify respective directions of the two pieces of magnetic flux generated by the coils **21** and **22**, and the directions of the two pieces of magnetic flux generated by the coils **21** and **22** are the same in the circumferential direction of the core **10**.

FIG. **3** illustrates a B-H curve and relative permeability of the core **10**, and the DC current to be applied to the coils **21**, **22** is set to generate, for example, a DC magnetic field of approximately 8 A/m. The value of the magnetic field, 8 A/m, is placed almost at the middle in a region where the relative permeability changes linearly relative to the magnetic field.

The coils **21**, **22** are assumed to have an identical number of turns, and an inductance L1 of the coil **21** and an inductance L2 of the coil **22** are equal. At a connection point P of the coil **21** and the coil **22**, an AC voltage with a superimposed DC voltage is generated by the excitation power supply **30** including the DC power supply **31** and the AC power supply **32**. An AC voltage Vd at the connection point P is expressed by the following, where Vac is an AC excitation voltage of the excitation power supply **30**:

$$Vd=(L2/(L1+L2))\cdot \mathrm{Vac} \tag{1}$$

and the inductances L1, L2 of the coil **21** and the coil **22** are equal when the external magnetic field is 0, so that the AC voltage Vd at the connection point P becomes ½ of the AC excitation voltage Vac.

In the meanwhile, when the earth magnetism M passes through the core **10** as illustrated in FIG. **1**, magnetic flux proportional to the earth magnetism M is generated in the portions of the core **10** where the coils **21**, **22** are placed. This causes the DC magnetic flux to be enhanced by each other in the portion where the coil **22** is placed and the DC magnetic flux to cancel each other in the portion where the coil **21** is placed. Therefore, magnetic flux density inside the core **10** in the portion where the coil **21** is placed changes and magnetic flux density inside the core **10** in the portion where the coil **22** is placed also changes.

When the magnetic flux density changes, as understood from FIG. **3**, the relative permeability of the core **10** changes. Since the magnetic flux density at the portion where the coil **22** is placed increases, the relative permeability decreases, whereas since the magnetic flux density at the portion where the coil **21** is placed decreases, the relative permeability increases. In response to each change of the relative permeability, the inductance L2 of the coil **22** decreases and the inductance L1 of the coil **21** increases. Accordingly, from the formula (1), the AC voltage Vd at the connection point P becomes less than the value assumed when the external magnetic field is 0, that is, Vd becomes less than ½ of the AC excitation voltage Vac.

As seen from the above, the AC voltage Vd at the connection point P of the two coils **21**, **22** changes depending on the input of the earth magnetism (external magnetic field), so that detection of the AC voltage Vd at the connection point P enables measurement of the earth magnetism.

A detection circuit **40** is connected to the connection point P of the coils **21**, **22**. The detection circuit **40** in this embodiment includes, as illustrated in FIG. **2**, a synchronous detector **41** and a low pass filter **42**. The synchronous detector **41** synchronously detects the voltage at the connection point P using the AC excitation voltage Vac of the excitation power supply **30**. The low pass filter **42** smooths an output of the synchronous detector **41**. The synchronously detected voltage becomes an output Vo after passing through the low pass filter **42**.

The detection circuit **40** is supposed to obtain the output Vo in such a manner. It is possible to measure the earth magnetism by the output Vo because the output Vo is responsive (proportional) to the magnitude of the earth magnetism.

As described above, in this embodiment, unlike the conventional flux gate type geomagnetic sensor, it is not required to excite the core **10** until the core is magnetically saturated, that is, the core **10** is not supposed to be magnetically saturated. Accordingly, the excitation current (DC current) may be small and the amplitude of the AC excitation voltage may also be small, thereby making it possible to reduce power consumption compared with the conventional flux gate type geomagnetic sensor.

FIG. **4** illustrates a functional configuration in a second embodiment of a geomagnetic sensor according to the present invention as a block diagram, and in this embodiment, a detection circuit **40'** is configured with a DC eliminator **43** that removes a DC component from the voltage at the connection point P of the coils **21**, **22**, a full wave rectifier **44** that rectifies the full wave of an output of the DC eliminator **43**, and a low pass filter **42** that smooths an output of the full wave rectifier **44**. Instead of the detection circuit **40** illustrated in FIG. **2**, it is also possible to employ the detection circuit **40'** of this type. The configuration may also use a half wave rectifier instead of the full wave rectifier **44**.

Next, descriptions are given to a third embodiment of a geomagnetic sensor according to the present invention. FIG. **5** schematically illustrates a configuration in the third embodiment, and FIG. **6** illustrates a functional configuration of the third embodiment as a block diagram.

Relative to the configuration illustrated in FIG. **1** and FIG. **2**, a feedback coil **23**, a feedback circuit **50**, and a current sense resistor **60** are added in this embodiment.

The feedback coil **23** is wound around the core **10** to make the core **10** magnetically-equilibrated. As illustrated in FIG. **5**, the feedback coil **23** is preferably disposed such that magnetic flux generated by the feedback coil **23** is parallel to the external magnetic field (the earth magnetism M). In FIG. **5**, an arrow c denotes a direction of the magnetic flux generated by the feedback coil **23**.

The feedback circuit **50** is connected to a subsequent stage of the detection circuit **40**. The feedback circuit **50** includes a reference voltage source **51** to generate a reference voltage, an adder **52** to add an output of the detection circuit **40** (output of the low pass filter **42**) and the reference voltage, and an amplifier **53** to amplify the output of the adder **52** and flow a feedback current to the feedback coil **23**.

The current sense resistor **60** converts the feedback current flowing through the feedback coil **23** to a voltage and outputs the voltage.

The reference voltage generated by the reference voltage source **51** is set up to cancel an output voltage output from the low pass filter **42** to 0 V when the external magnetic field is 0. Accordingly, the feedback current becomes 0 when the external magnetic field is 0, and a current does not flow through the feedback coil **23**. An output of the current sense resistor **60** becomes 0 V.

In the meanwhile, when the earth magnetism M is input as illustrated in FIG. **5**, the output of the low pass filter **42** becomes less than the output assumed when the external magnetic field is 0, as described in the first embodiment. Accordingly, the output of the adder **52** becomes a negative voltage. This causes a negative feedback current to flow through the feedback coil **23**, and the core **10** becomes a magnetic equilibrium state relative to the earth magnetism M. The feedback current is converted to a voltage by the current sense resistor **60** and then the voltage is output, and it is possible to measure the input earth magnetism in this embodiment by the output of the current sense resistor **60**. The detection circuit **40** may also be replaced with the detection circuit **40'**.

Although embodiments of the present invention have been described above, the core **10** is not limited to a toroidal core and may also be in another shape, and for example, may also be a core in a quadrilateral shape. In addition, instead of the DC power supply **31**, a DC constant current source may also be used.

What is claimed is:

1. A geomagnetic sensor, comprising:

a core that constitutes a closed magnetic circuit;

two coils that are wound around the core in positions facing each other and that are connected in series to generate magnetic flux in a same circumferential direction in the core;

an excitation power supply that applies an alternating current with a superimposed direct current to the two coils; and

a detection circuit that is connected to a connection point of the two coils,

wherein the detection circuit includes a synchronous detector that synchronously detects a voltage at the connection point using an alternating current excitation voltage of the excitation power supply, and a low pass filter that smooths an output of the synchronous detector.

2. The geomagnetic sensor according to claim **1**, further comprising:

a feedback coil;

a feedback circuit; and

a current sense resistor,

wherein the feedback coil is wound around the core to make the core magnetically equilibrated,

the feedback circuit includes a reference voltage source to generate a reference voltage, an adder to add an output of the low pass filter and the reference voltage, and an amplifier to amplify an output of the adder and flow a feedback current to the feedback coil, and

the feedback current is converted to a voltage by the current sense resistor and then the voltage is output.

3. A geomagnetic sensor, comprising:

a core that constitutes a closed magnetic circuit;

two coils that are wound around the core in positions facing each other and that are connected in series to generate magnetic flux in a same circumferential direction in the core;

an excitation power supply that applies an alternating current with a superimposed direct current to the two coils; and

a detection circuit that is connected to a connection point of the two coils,

wherein the detection circuit includes a direct current eliminator that removes a direct current component of a voltage at the connection point, a full wave rectifier that rectifies full wave of an output of the direct current eliminator, and a low pass filter that smooths an output of the full wave rectifier.

4. The geomagnetic sensor according to claim **3**, further comprising:

a feedback coil;

a feedback circuit; and

a current sense resistor,

wherein the feedback coil is wound around the core to make the core magnetically equilibrated,

the feedback circuit includes a reference voltage source to generate a reference voltage, an adder to add an output of the low pass filter and the reference voltage, and an amplifier to amplify an output of the adder and flow a feedback current to the feedback coil, and

the feedback current is converted to a voltage by the current sense resistor and then the voltage is output.

5. A geomagnetic sensor, comprising:

a core that constitutes a closed magnetic circuit;

two coils that are wound around the core in positions facing each other and that are connected in series to generate magnetic flux in a same circumferential direction in the core;

an excitation power supply that applies an alternating current with a superimposed direct current to the two coils; and

a detection circuit that is connected to a connection point of the two coils,

wherein the detection circuit includes a direct current eliminator that removes a direct current component of a voltage at the connection point, a half wave rectifier that rectifies half wave of an output of the direct current eliminator, and a low pass filter that smooths an output of the half wave rectifier.

6. The geomagnetic sensor according to claim **5**, further comprising:

a feedback coil;

a feedback circuit; and

a current sense resistor,

wherein the feedback coil is wound around the core to make the core magnetically equilibrated,

the feedback circuit includes a reference voltage source to generate a reference voltage, an adder to add an output of the low pass filter and the reference voltage, and an amplifier to amplify an output of the adder and flow a feedback current to the feedback coil, and

the feedback current is converted to a voltage by the current sense resistor and then the voltage is output.

7. A geomagnetic sensor, comprising:

a core that constitutes a closed magnetic circuit;

two coils that are wound around the core in positions facing each other and that are connected in series to generate magnetic flux in a same circumferential direction in the core;

an excitation power supply that applies an alternating current with a superimposed direct current to the two coils; and

a detection circuit that is connected to a connection point of the two coils,

wherein the excitation power supply applies the alternating current with the superimposed direct current to the two coils in a manner such that the core is not magnetically saturated.

8. The geomagnetic sensor according to claim **7**,

wherein the superimposed direct current is set so as to generate a magnetic field corresponding to a midpoint of a range in which relative permeability changes linearly with response to a magnetic field.

9. A geomagnetic sensor, comprising:

a core that constitutes a closed magnetic circuit;

two coils that are wound around the core in positions facing each other and that are connected in series to generate magnetic flux in a same circumferential direction in the core;

an excitation power supply that applies an alternating current with a superimposed direct current to the two coils; and

a detection circuit that is connected to a connection point of the two coils,

wherein the superimposed direct current is set so as to generate a magnetic field corresponding to a midpoint of a range in which relative permeability changes linearly with response to a magnetic field.

* * * * *